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ADVANCED TRANSPORTATION SYSTEM STUDY

Manned Launch Vehicle Concepts for Two Way Transportation System Payloads to LEO

PROGRAM COST ESTIMATES DOCUMENT (DR-6)

Contract NAS8-39207

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ADVANCED TRANSPORTATION SYSTEM STUDY

Manned Launch Vehicle Concepts for Two Way Transportation System Payloads to LEO

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Submitted by:

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Space Systems Division
Huntsville Operations

FORWARD

This report is submitted in compliance with DR-6 of Contract NAS8-39207, Advanced Transportation System Studies for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center. The report describes Rockwell International's cost analysis results of Manned Launch Vehicle Concepts for Two Way Transportation System Payloads to LEO during the Basic and Option 1 contract period of performance. This report is submitted as a subsection of the Final Report (DR-4).

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1.0 SCOPE

1.1 Contract Tasks:

Advanced Transportation Systems Study (ATSS) Task Area 1 (TA1) costing analysis task (SOW 5.3) consisted of three concurrent sub tasks which resulted in the submission of two reports; the Work Breakdown Structure (WBS) and a WBS Dictionary (DR-5), and the Program Cost Estimates Report (DR-6). The sub tasks were as follows:

Sub task 3.1 Build Work Breakdown Structure (WBS) and WBS Dictionary
Sub task 3.2 Develop Top-Level Cost Estimating Relationships (CERs)
Sub task 3.3 Estimate (manned) launch system cost elements

1.2 Launch Vehicle Concepts Costed During The Contract

Concepts which were examined in this study included the following launch systems:

Space Shuttle
PLS with either the ALS-C6 or with the NLS-2 50 Klb booster
ESA's Ariane 5
CIS's Zenit (SL-16), Proton (SL-13) & Energia (SL-17)
NLS-2 50 Klb Launch Vehicle derivatives (Four derivatives evaluated)
Two-Stage Liquid Rocket Booster (LRB) derived launch vehicle
(an F-1A booster stage with a J-2S second stage (S-IVB))
Cargo Transfer and Return Vehicle (CTRV)

1.3 Organization of DR-6 Report

For each of the individual launch vehicles (or group of concepts) costed during this reporting period, this report contains a mini-report comprised of a unique

Section 1 (Approach, methodology & rationale),
Section 2 (Summary cost presentations),
Section 3 (Cost estimates by WBS element), and
Section 4 (Total program funding schedule)

as appropriate for that particular vehicle or concept. Each individual mini-report details the groundrules & assumptions that were unique to that vehicle, the cost estimating methodology used and its basis of estimate, and such cost details as were estimated in each case (e.g., cost elements, cost drivers, cost sensitivities, cost/performance tradeoffs, etc.)

2.0 BACKGROUND INFORMATION

2.1 Groundrules, Assumptions & Conventions

The structure for all cost estimates is reflected in the WBS (and accompanying WBS Dictionary) which was agreed to among MSFC and the ATSS contractors (in particular the TA4 contractor, General Dynamics). The WBS was submitted in September, 1992 as a contract approved document (DR-5). Also agreed to among the parties was a cost based on constant Fiscal Year 1993 Dollars. The cost estimates reflect the system Cost To Government, including contractor fee, government support & contingency. Adjustments for "New Ways of Doing Business" were not credited unless specifically stated, the CERs were thus based on actual cost data.

2.2 Significant Issues:

The nature of TAI's costing task required us, on many of the systems examined during this period, to synthesize individual cost estimates for one or more of the elements (e.g., one study's estimate for a crew module, another study's estimate for its launch vehicle) of an operational system. Frequently, those element-level cost estimates had been prepared by other contractors, each working under its own peculiar costing groundrules, assumptions and conventions. A non-trivial portion of TAI's job, therefore, was to reconcile those estimates prepared by "other" sources into a standard WBS that had been jointly agreed to by ATSS contractors and MSFC/PP and that described the cost of a complete operational system. Several significant issues, which limit the degree of cost comparability between systems, arose during our attempts to reconcile and synthesize cost estimates prepared by "other-than ATSS" sources:

<u>Non-Comparable "Bases Of Estimates"</u>
The "basis of estimate" underlying any one contractor's cost estimate was rarely comparable to the basis of estimate for any other contractor's cost estimate. Very few cost estimates were based on actual (historic) cost data from analogous real programs, which would have provided the most credible basis of estimate. Several "other study" estimates were contingent on third-party estimates. Not infrequently, that third party happened to be the sponsor of another potential new start system (e.g., the PLS's operational cost effectiveness relied heavily on the ALS's $1,000 per pound to orbit C6 booster). Finally, some cost estimates barely qualified for the term "cost estimate", but were simply stated as "targets" or "goals". Compounding the non-comparability in bases of estimate, there remains the question of discounting historic cost estimating relationships (CERs), i.e., taking credits for "new ways of doing business", in the absence of any compelling factual evidence that such a credit is warranted.

Omissions & Exclusions

The most pervasive source of non-comparability between cost estimates from different programs and/or study contractors arose from the simple question: "What's in" those numbers, and more importantly "What's not ?" Cost estimates obtained from other programs were virtually never compatible in their overall program content (e.g., number and type of design reference missions, overall mission models and annual traffic rates, level of design maturity and technology readiness levels). For example, several proponents of new launch systems (their potential developer and/or operators) implicitly transferred substantial costs out of the launch system and onto the end user. This is in effect an implicit assumption that the mission sponsor would redesign his/her payload to withstand higher accelerations during the ascent or that the payload could do without such launch vehicle provided services as electrical power, cooling, data processing, communications, etc. during launch processing, launch and ascent. Others, either by assumption or groundrule, allocated functional requirements to non-existent hardware that "would be available" from other programs (e.g., assumed that a space-resident orbital transfer vehicle would be there (free) to transport cargo from its point of deployment to its final Space Station destination). Cost estimates for some of the "next generation" launch vehicle concepts appear to have been prepared as if the embodied technology were fully matured for the application. That is, "known unknowns" (even "unknown unknowns") were treated as "state of the art" without any corresponding increments (appropriate risk adjustments) to expected cost.

Absorption (Full) versus Marginal Costing

There was, however, at least one area in which the groundrules and assumptions used by sponsors of new launch systems was almost universally consistent -- that was in their treatment of infrastructure (standing army) costs. Virtually without exception their groundrule was to let the Space Shuttle program pay for maintaining the infrastructure (full absorption cost), but allow the new program to obtain hardware at its marginal cost" (e.g., the next External Tank at $15M). Not coincidentally, some concepts that relied on marginal costing for their justification were intended to replace the Space Shuttle. Which program would pick up the annual fixed infrastructure costs when the Shuttle was gone was never addressed.

Costs of Manned Spaceflight

No sponsor of a new launch system (repeat, no sponsor of a new launch system) addressed either the cost impact of man-rating their proposed launch vehicle or the expected loss (cost of unreliability) associated with transporting crew into space. Nor did any study fully acknowledge (accept) the extra costs associated with NASA's manned spaceflight awareness criteria.

Unmanned Launch Vehicles	*Manned Launch Vehicles*
• **no crew-unique subsystems**	• **crew-unique subsystems** ... crew escape/safe haven provisions ... intact abort modes thru mission ... ECLSS, EVA, "cockpit"
• **accept *demonstrated* reliability** ... insure against $ loss	• **ill-defined *man-rated* criteria** ... safe recovery, any credible emergency ... *manned spaceflight awareness* "highest possible reliability" extensive test & verification inspection & documentation
• **core ballistic trajectory**	• **recovery from orbit** ... de-orbit, re-entry & landing systems
• **limited (nil) on-orbit operations**	• **hours/days of on-orbit operations** ... fuel cells, waste management ... special "tools", e.g., RMS, EMU ... doors that open & close ... intense mission planning &control
an operations orientation	*a perpetual DDT&E environment*

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Figure 2.3-1 Manned launch vehicle differences which drive costs.

3.0 BASIC REQUIREMENTS

3.1 Space Shuttle

3.1.1 Costing Approach, Methodology & Rationale

Methodology: Parametric

WBS Level: Major Elements, e.g., External Tank, Orbiter, Launch & Landing

Primary Sources of Data:
Stages To Saturn. NASA History Series SP-4206, Appendix D
Economic Analysis of the Space Shuttle System. Executive summary., NASW-2081
Assessment of Space Shuttle Program Cost Estimating Methods., H. C. Mandell, Jr.
Space Shuttle Zero-Base Operations Cost Study. , June 1991

Groundrules & Assumptions
Development Cost - actual Space Shuttle program costs
Funding Profile - actual Space Shuttle program funding profile
Operations & Support, Cost Per Flight - NASA's *Zero-Base Operations Cost*
Fiscal Year 1993 Dollars - sources converted at OMB escalation rates
New Ways of Doing Business - not credited

Test Philosophy: as tested, consistent with *Manned Spaceflight Awareness*

Operational Philosophy: operational , manned, partially-reusable

Management Approaches: institutionalized support

Original Development WBS
- Orbiter
- JSC Program Support
- Space Shuttle Main Engine
- Solid Rocket Booster
- External Tank
- MSFC Systems Management
- Launch & Landing
- NASA Headquarters
- OMB Allowance

Summary of Cost Trades: see Mathematics' "Justification" for Space Shuttle

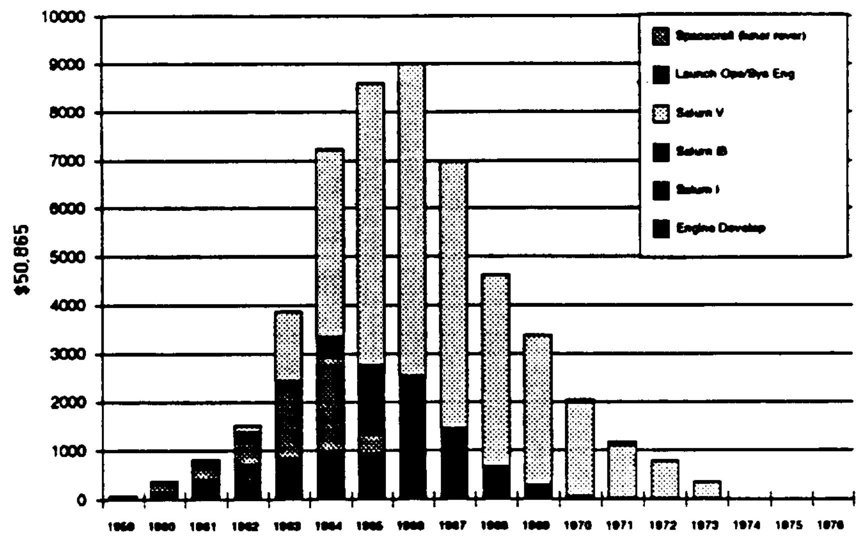
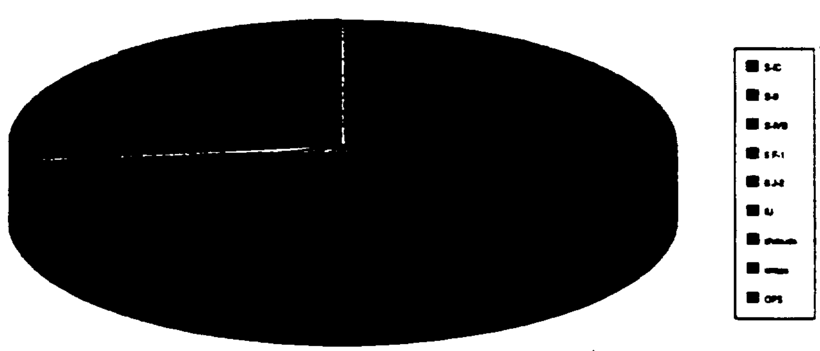


Figure 3.1-1 Saturn Launch Vehicles Cost over $50B '93

structures, propulsion & engines drive hardware cost



Saturn V orbited 275,000 pounds into a 100 nmi circular orbit at an average cost of ~$700M'93 per flight over 13 launches ... a transportation cost of just over $2,500'93 per pound

Figure 3.1-2 75% of Saturn V cost per flight was for expendable hardware.

Expendable Launch Vehicle	*Reusable Launch Vehicle*
• **continuous production run** ... new components each flight ... continuous product improvement ... changes off-line at factory ... perpetual spares inventory	• **limited (finite) production run** ... "used" components each flight ... infrequent **on-line** "block changes" ... limited spares, cannibalization
• **no recovery systems**	• **recovery subsystems** ... re-entry thermal protection ... wings, landing gear, parachutes ... avionics (GN&C) re-entry, landing
• **45 minute design life**	• **multiple use design life**
• **no "recover/refurbish" army**	• **army to recover & refurbish elements**
• **LV is small fraction of stack value** ... insurable stack ... precautions to protect payload	• **LV is large fraction of stack value** ... uninsurable stack ... precautions to protect LV
lower annual fixed cost, but relatively higher variable cost/ flight	*higher annual fixed cost, but relatively lower variable cost/flight*

Figure 3.1-3 Differences between expendable & reusable launch vehicles.

3.1.2 Summary Cost Presentations

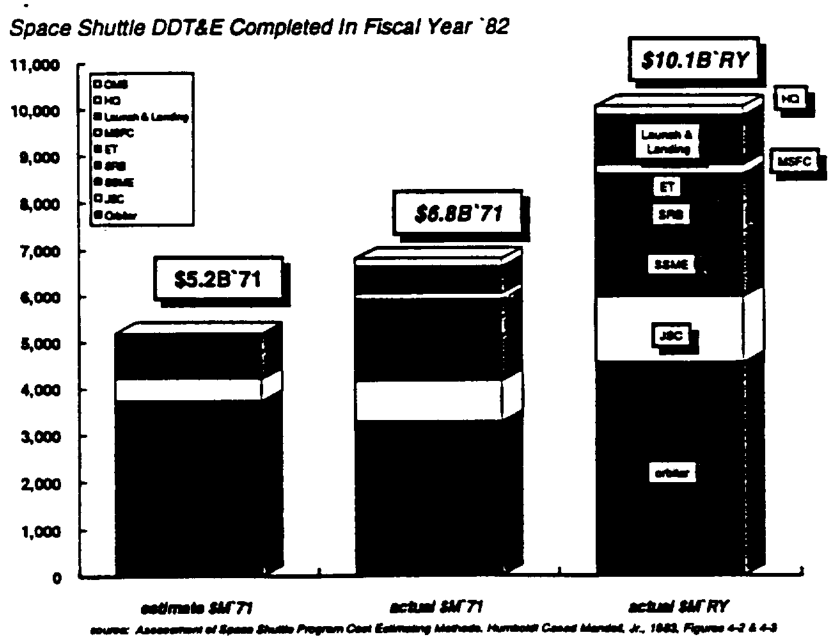
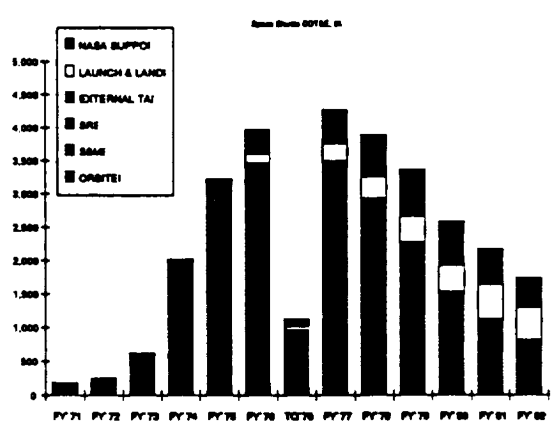


Figure 3.1-4 Space Shuttle DDT&E, Actual Costs vs. 1972 Estimates



Project	actual $M'RY	escalate to $M'93
Orbiter	4,560.0	*14,186*
JSC	1,413.1	*3,786*
SSME	1,411.8	*4,162*
SRB	603.4	*1,688*
ET	628.0	*1,778*
MSFC	186.8	*494*
L&L	1,059.4	*2,590*
HQ	198.8	*732*
Total	10,061.3	*29,415*

source data: Assessment of Space Shuttle Program Cost Estimating Methods, Humboldt Casad Mandel, Jr., 1983, Appendix F

Figure 3.1-5 Space Shuttle DDT&E Cost in FY93 Dollars

• **comprehensive "bottoms-up" assessment of Space Shuttle operating costs**

... determine resource requirements for flight rates from 1 to 10 per year
... directed by Space Shuttle Program Office and Office of Space Flight
... seventeen $10M+ project offices reviewed in detail (98% of operating costs)
... results presented to Dr. Lenoir, July 2, 1991

• **groundrule: capability NOT maintained if not required to meet specific flight rate**

... Orbiter Vehicles
... Mobile Launch Platforms
... Launch Pads & other (VAB cells, ET checkout cells, GSE)

• **assumes continuing minimum production rates for specified elements**

... External Tank (4 units per year)
... Solid Rocket Motor/Solid Rocket Booster (2 units per year)
... Space Shuttle Main Engine (3 flights per year)
... astronaut corps (40 astronauts)

Figure 3.1-6 NASA's Zero-Base Operations Cost Study, July 1991

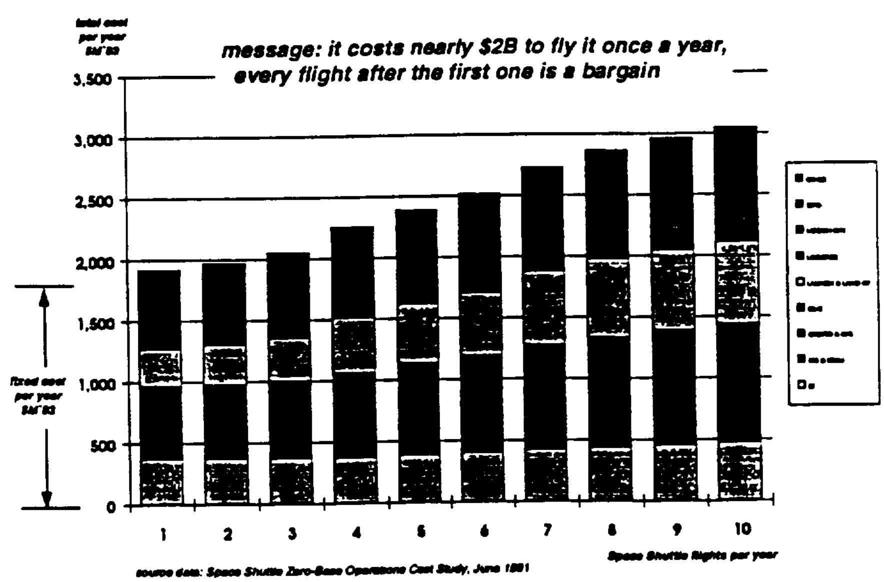


Figure 3.1-7 Shuttle Annual Cost is Dominated by Fixed Support Costs

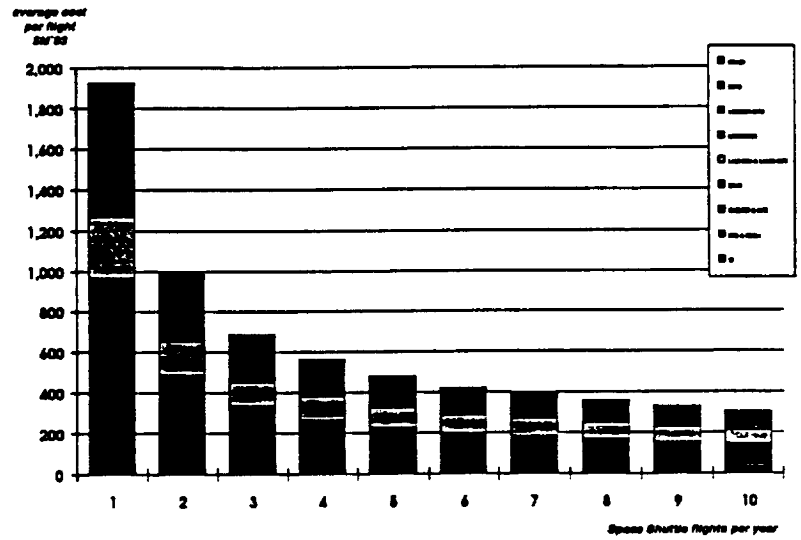


Figure 3.1-8 Shuttle Average Cost per Flight Drops as Flight Rate Rises

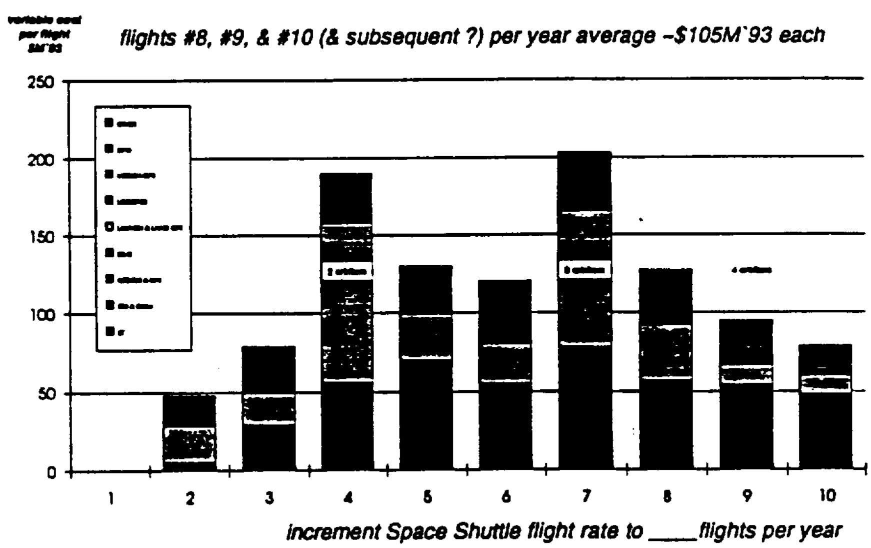


Figure 3.1-9 Shuttle Variable Cost per Flight (Marginal cost of next flight)

3.1.3 Cost Estimates by WBS Element

Element	Fixed Cost Per Year $M'93	Variable Cost Per Flight $M'93	SEE $M'93	r^2
ET	339.1	12.0	12.0	0.91
SRB/RSRM	317.4	32.0	11.7	0.99
Orbiter & GFE	128.2	7.7	4.2	0.97
SSME	76.2	6.1	3.2	0.97
Launch & Landing	250.3	45.6	27.3	0.97
Logistics	98.1	10.1	4.0	0.98
Mission Ops	227.2	9.4	2.7	0.99
SSPO	122.7	6.0	2.4	0.98
other	160.9	8.4	4.3	0.98
Space Shuttle	*1,720.2*	*137.3*	*48.0*	*0.99*

Figure 3.1-10 Space Shuttle Element Cost per Flight ($M93)

3.1.4 Total Program Funding Schedules

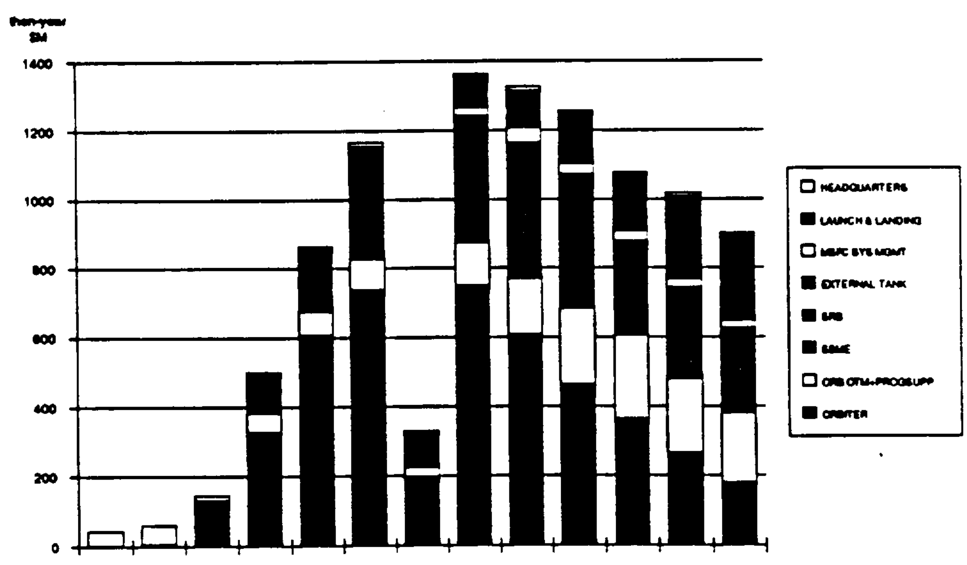


Figure 23.1-11 Space Shuttle Element Funding Profile (real-year $M)

3.2 Personnel Launch System (PLS) with the Advanced Launch System (ALS-C6) and the National Launch System (NLS-2) Boosters

3.2.1 Costing Approach, Methodology & Rationale

Methodology

Element level cost estimates for PLS/ALS/NLS were not generated by TA1. For each individual element, cost estimates had previously been generated by study contractors, and these were used by TA1 as they had been documented in each study's final report. Apparent deficiencies (e.g.., unrealistic groundrules, inconsistent program content, incredible cost per flight or dollar per pound quotes, etc.) in the source cost estimates were noted, but were not corrected by TA1. Each study's cost estimate was re-aligned into the approved ATSS WBS, was escalated to constant FY 1993 dollars, and was combined with the other elements to constitute an estimate for the operational system. NASA "wraps" for contractor fee, government support and contingency were added.

Primary Sources of Data:

NASl-18975 Personnel Launch System/Advanced Manned Launch System Life Cycle Cost Analysis. , DRD-7, September 10, 1990

Groundrules & Assumptions

The source cost estimates were escalated to Government Fiscal Year 1993 Dollars. The source specifically excludes cost of man-rating the booster and of facilitizing ALS for PLS. The source uses ALS-C6 @ $43.3M ('89) per launch based on USAF/SD quote. The source assumes "airline operations" resulting in a peak operations staffing of less than 1,000 EP.

Test Philosophy:	4 to 6 PLS test flights prior to initial operational capability
Operational Philosophy:	"airline operations"
Cost Avoidance Techniques:	numerous, e.g., fecal bags in lieu of "potty"
Management Approaches	high tolerance for risk, e.g., fabricating large graphite polyimide structures
Representative CERs:	see Section 3.2.3
Cost Factors:	excludes necessary costs, e.g., development test facilities for water landing tests

3.2.2 Summary Cost Presentations

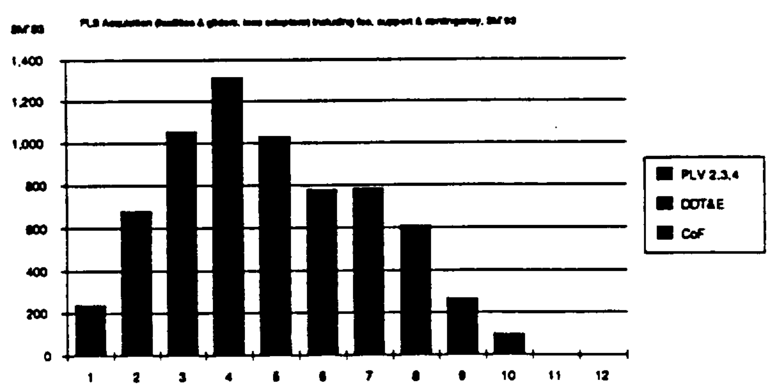
***source data:** NAS1-18975 Personnel Launch System/Advanced Manned Launch System, Life Cycle Cost Analysis DRD 7, September 10, 1990*

- Program consists of:
  - ... PLS facilities
  - ... 4 Personnel Launch Vehicles (PLVs), total 8 flights per year
  - ... 141 expendable PLS/ALS adapters with launch escape
- Source cost data based on ***DRM-1 only*** (*bare-bones* SSF crew rotation)
- Source ***assumes*** Advanced Launch System (ALS) operational capability
  - ... ALS developed independent of (at no cost to) PLS
  - ... ALS C-6 available for orbital flight test of PLS glider
  - ... PLS uses ALS @ ~$52.1M'93 per flight (input from USAF/SSD)
- Source makes ***no provision*** for man-rating launch vehicle
- Source ***assumes*** "airline operations" of PLS/ALS

"There is no existing manned space system that has demonstrated low cost operations. In order to substantiate a low cost operations estimate, it was necessary to define PLS operations with respect to a non-aerospace culture, namely airline operations."

Figure 3.2-1 Personnel launch System (PLS) Cost Estimates

Assumes ALS development prior to and independent of PLS
No provisions were made for man-rating launch vehicle



NOTE: PLS adapter production treated herein as an element of recurring Cost Per Flight

Figure 3.2-2 DDT&E and CoF for PLS Spacecraft, $6.0B'93

ALS C-6 cost per launch (~$44M'89) data were input to PLS/AMLS by USAF

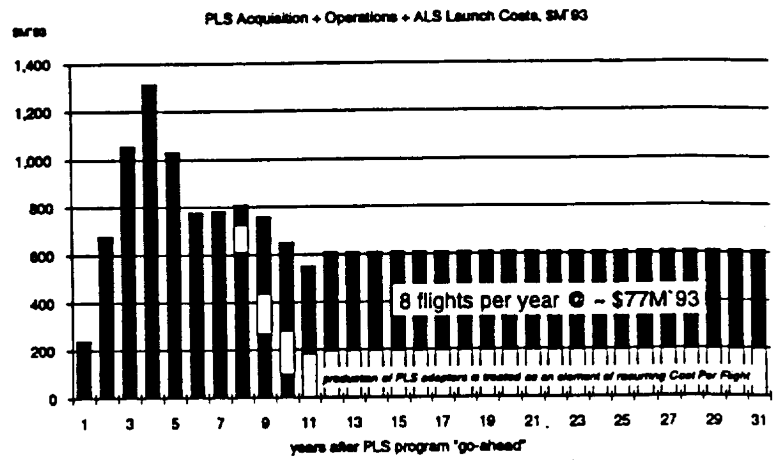
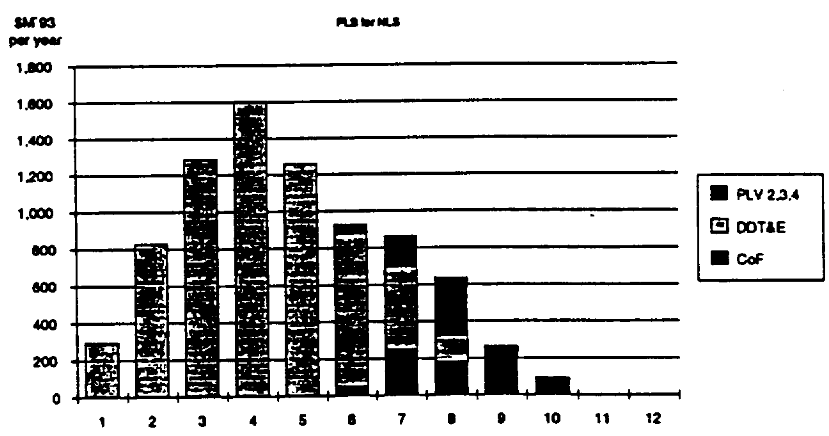


Figure 3.2-3 Advanced Launch System (ALS) was Baseline Booster for PLS



Assumes NLS development prior to and independent of PLS
No provisions for man-rating launch vehicle have been made

Figure 3.2-4 Use of NLS Booster Increases PLS DDT&E to $7.3B

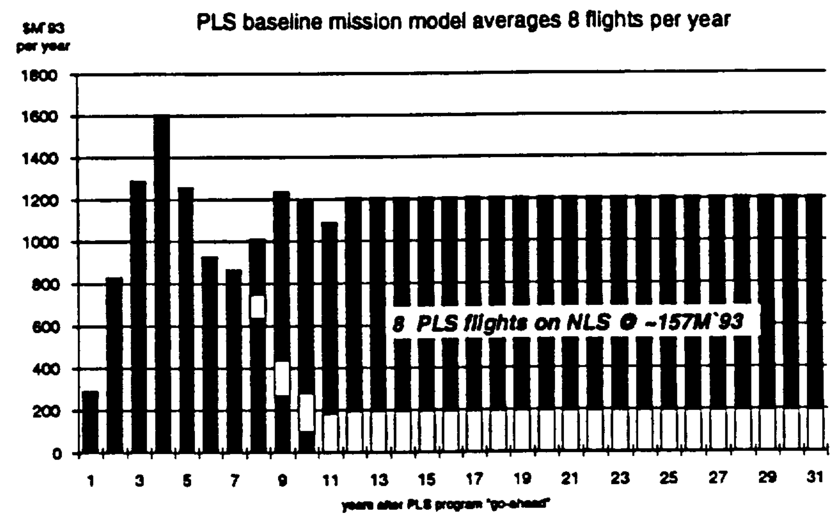


Figure 3.2-5 NLS-2 Booster Costs Dominate PLS Cost per Flight

3.2.3 Cost Estimates by WBS Element

Cost Estimates for Personnel Launch System (PLS) Element

Acquisition Cost	$ 6,862 (M'93)
Non-Recurring CoF	487
Non-Recurring DDT&E	5,480
Recurring Production (PLS #2,#3 & #4)	895
Recurring Cost Per Flight	$101 M'93 per year
	+ $10 M'93 per flight

Cost Estimates for Advanced Launch System (ALS) Element (source USAF/SD)

Acquisition Cost:	estimate not provided by USAF/SD
Recurring Cost Per Flight	$ 42 (M'93) per year
	+ $ 47 (M'93) per flight

NOTE: costs to man-rate ALS-C6 and to facilitize ALS for PLS manned operations are not included

Cost Estimates: National Launch System (NLS) Element (source NLS Cost Status, January 15, 1992)

Acquisition Cost	$ 5,896 (M'91, per NLS convention)
Non-Recurring CoF	341
Non-Recurring DDT&E	5,555
Recurring Production:	included in recurring cost per flight
Recurring Cost Per Flight:	$315 (M'93) per year
	+ $107 (M'93) per flight

NOTE: Costs to man-rate the NLS-2 50Klb launch vehicle and to facilitize the NLS launch site for manned PLS operations are not included. It is assumed that the Space Shuttle program absorbs annual fixed costs associated with External Tank production. A "credit" for "new ways of doing business" (NWODB) was also assumed.

3.2.4 Total Program Funding Schedules

See Section 3.2.2

3.3 ESA's Ariane 5 and the CIS's Zenit (SL-16), Proton (SL-13) & Energia (SL-17) Boosters

At the direction of NASA/HQ, NASA/JSC's Manned Transportation System (MTS) study was evaluating foreign launch systems for potential use in America's manned-space program. In mid-July of 1992, MTS asked NASA/MSFC's Advanced Transportation Systems Study (ATSS) Task Area 1 (TAl) contractor to provide technical data, including cost estimates, for the European Space Agency's (ESA's) Ariane 5 and the Commonwealth of Independent States' (CIS's) Soyuz, Proton and Energia launch vehicles.

3.3.1 Costing Approach, Methodology & Rationale

Methodology

Rough-Order-of-Magnitude (ROM) parametric estimates of non recurring (NR) development costs for ESA's Ariane 5 and estimates of operational cost per flight (CPF) for Ariane 5, Soyuz, Proton and Energia are summarized in Table 1, below. Cost estimates are dimensioned in millions of fiscal year 1992 US dollars ($FY'92M) at mid-1992 currency exchange rates and assume a circa-1998 launch date. Generally, estimates were made at the launch vehicle-level (rather than element subsystem-level) consistent with degree of vehicle technical definition available.

Primary sources of data:

1) *International Reference Guide To Space Launch Systems*, S. J.. Isakowitz, AIAA, 1991,
2) *Aviation Week & Space Technology*, (various articles)
3) *Soviet Year in Space*, N. Johnson, Teledyne Brown Engineering
4) Anecdotal information regarding conditions in CIS's space industry as of July '92 provided through the U.S. Department of Commerce.

These foreign launchers have been priced/costed at their commercial equivalent value, i.e., at their replacement costs assuming an on-going business. As a result, particularly for CIS's Soyuz, Proton and Energia, these cost estimates are substantially higher than the "bargain" rates quoted in mid-1992 by Glavcosmos.

Cost Estimates Do *NOT* Include

... extra costs to **MAN-RATE** launch vehicle
... extra costs to operate in *Manned Spaceflight Awareness* environment

Rough Order of Magnitude (ROM), parametric CER (SEE -+- 20%)

... estimates in constant-year 1992 US$, commercial equivalent launch, circa 1998
... Ariane 5 development (DDT&E)
... Ariane 5, Proton & Energia cost per flight

Consistent With Level of Design Definition

... launch vehicle
... payload capability (maximum) at launch site latitude
... gross lift-off weight
... stage level data incomplete, inconsistent

Foreign Currency Exchange Rates

Primary Sources of Data

... *International Reference Guide To Space Launch Systems*, AIAA
... *Soviet Year In Space*, TRW
... *Aviation Week & Space Technology*
... anecdotal, US DoC

Figure 3.3-1 Groundrules & Assumptions for Foreign Launch Vehicle Costs

CONSIDERATIONS UNIQUE TO FOREIGN VEHICLES

* Methodology
* Data Base Limitations
* Exchange Rates
* Foreign Productivity (man-year equivalent)
* *ONLY SOYUZ Has Actually Launched Crew*

European Space Agency (ESA) & Ariane

* Commercial Operations
* Exchange Rates
* Hermes De-Scoped (unmanned X2000)
* Ariane 5 Man-Rating ?

Commonwealth Independent States (CIS) & Soyuz, Proton & Energia

* Political Stability
* Launch Rates
* Free-Market Economics (labor/factor mobility)
* Productivity
* Exchange Rates

Figure 3.3-2 Unique Considerations For Foreign Launch Vehicle Costs

Estimates are dimensioned in $FY'92M at mid-1992 foreign currency exchange rates. Estimates for ESA's Ariane program were originally developed in ESA "accounting units" and translated to US dollars at average 1990-1991 exchange rates between French francs, German D-marks and Italian lira to neutralize the effects of exchange rate fluctuations (i.e., currency risks between dollars and "accounting units"). These average $FY'90-$FY'91 were subsequently converted to $FY'92. The problem of converting historical CIS costs, dimensioned in rubles, to $FY'92 was more profound. The existence of different types of rubles (domestic and international), coupled with extremely volatile exchange rates today resulting from rampant inflation within CIS make direct conversion of ruble-based costs to dollar-based costs an exercise in futility. Therefore, estimates for CIS's launch vehicles were developed using a free-market man-year equivalent basis which assumes that input factors (particularly labor) to CIS's space industry were (are) exactly as productive as European and American aerospace workers were (are). Given that assumption, CIS hardware and services can be valued at free-market costs.

Launchers were costed at commercial equivalent values assuming circa-1998 launch While CIS may, in the very short-term, be willing to price its launch services below replacement costs (e.g., Glavcosmos has recently offered Proton launches for $56M) to obtain hard currency, it cannot afford to do so in the long run. If CIS continues its move toward free-market economics, its input costs (for materials, labor and capital) will rise sharply and that, in turn, will force its offering prices to rise.

Vehicle specific technical descriptions were used as stated in references. Although minor errors and inconsistencies were found in some technical descriptions (e.g., stage weights), they were ignored in favor of data comparability across vehicles. No attempt was made to "normalize" stated performance capabilities to a standard orbital inclination (e.g., Proton capability was taken at Baikonur, with no decrement for plane change to a standardized 28.5 degrees inclination; nor was any increment given for enhanced Proton capability if it were launched from Cape York).

For existing commercial ELVs, Cost Per Flight (CPF) quotes were used as stated. CPF estimates were not reconciled against other (contradictory) sources. Commercial Titan launches have been quoted as low as $111.5M and $108.4M (AW&ST 16 July 90, p24), compared to $130M-$150M without an upper stage as cited by Isakowitz. Element-level data for foreign launchers has been found to be very inconsistent. For example, the sum of the Ariane 5 P230 solid rocket motor costs and the HM-60 cryogenic engine costs totaled more than entire lower composite for the Ariane 5 launcher.

Extra man-rating" and manned operations costs were not estimated. The suitability of some foreign launchers for manned space flight is highly suspect. While CIS's Atlas-class Soyuz (SL-4) has routinely transported crew capsules and Salyut/Mir space station provisions into space from Baikonur since 1963, it is the only one of these launch vehicles to have actually demonstrated its manned space flight capability. CIS's Titan class Proton (SL-13) boosted seven Salyut-series space stations into low-Earth-orbit (LEO) between 1971 and 1985 and lofted the Mir space station in 1986, but has not been used for manned space flight nor are there known plans to "man-rate" the vehicle. CIS's Saturn V-class Energia (SL-17) has boosted the Buran space shuttle orbiter into LEO, but has flown only twice (both unmanned missions) and is in jeopardy of cancellation for lack of payloads. ESA's Titan-class Ariane 5, under development as a man-rated vehicle to support ESA's Hermes in addition to its primary role as a commercial launcher, is at least three years away from first flight and is vulnerable to capability change.

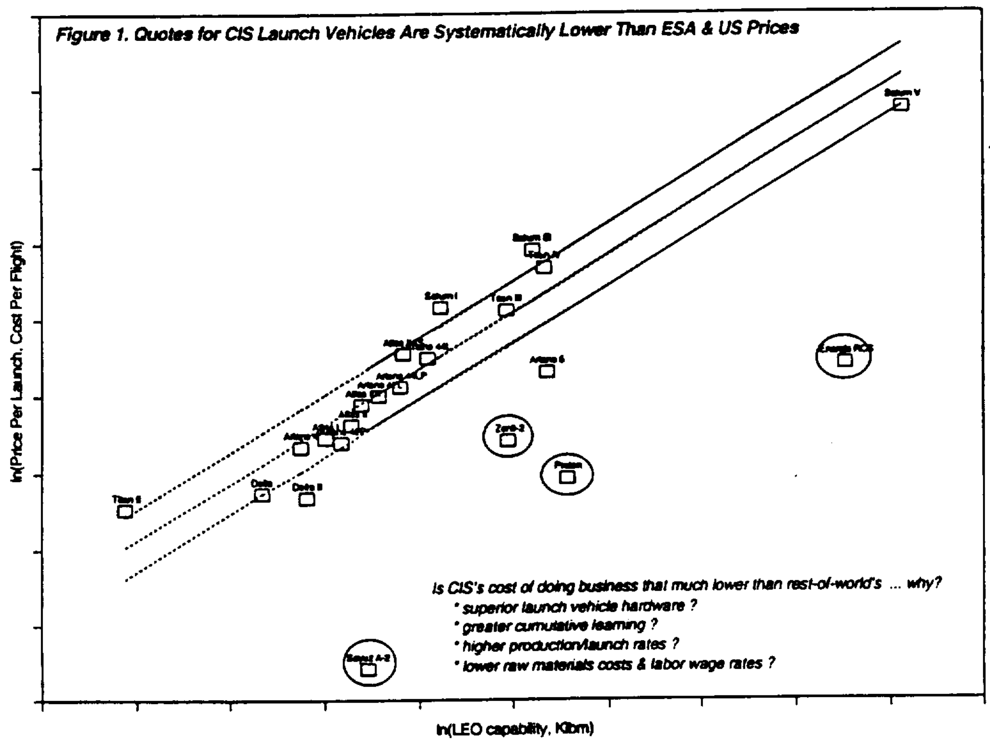


Figure 3.3-3 Quotes for CIS Boosters Lower Than ESA and USA Boosters

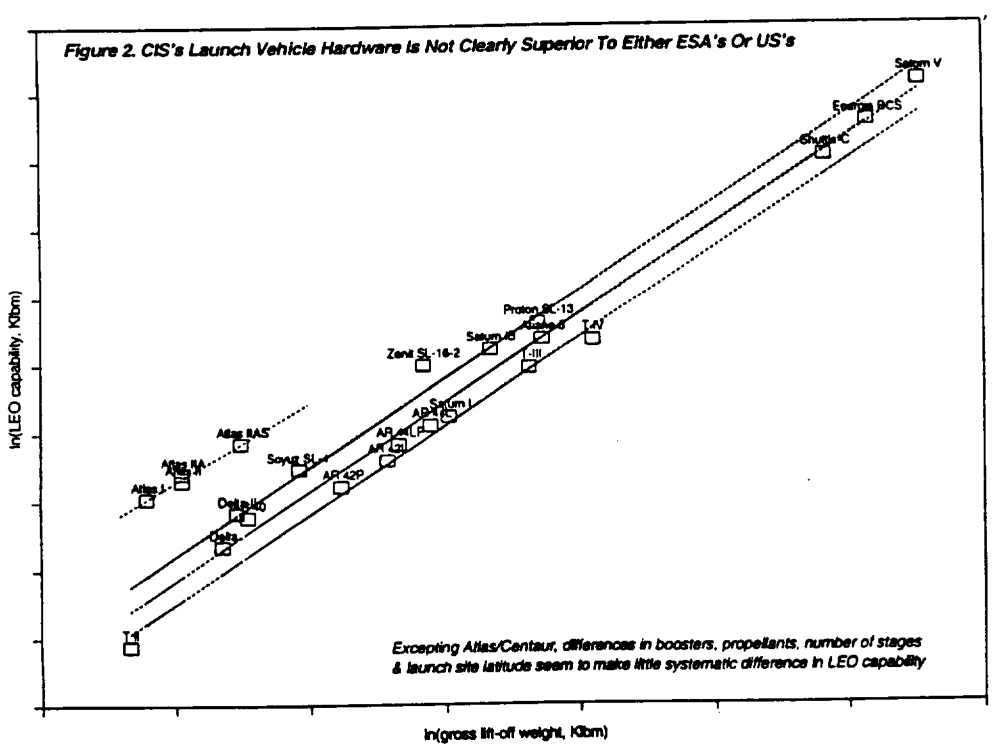


Figure 3.3-4 CIS Boosters are not Superior to ESA and USA Boosters

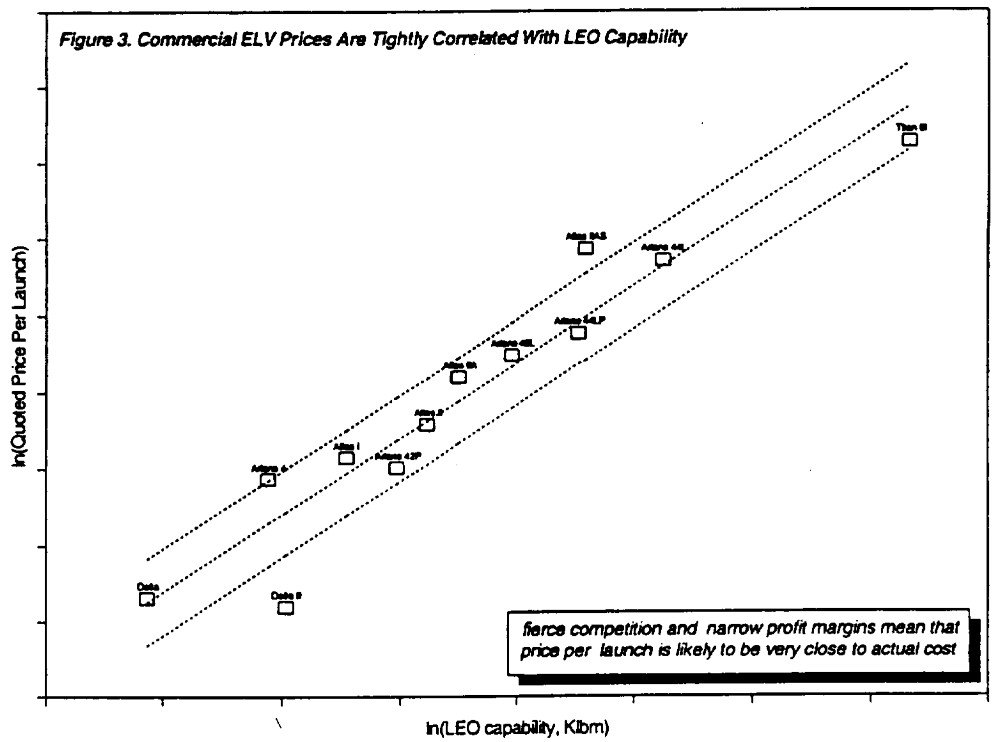


Figure 3.3-5 Commercial ELV Prices Tightly Correlated with LEO Performance

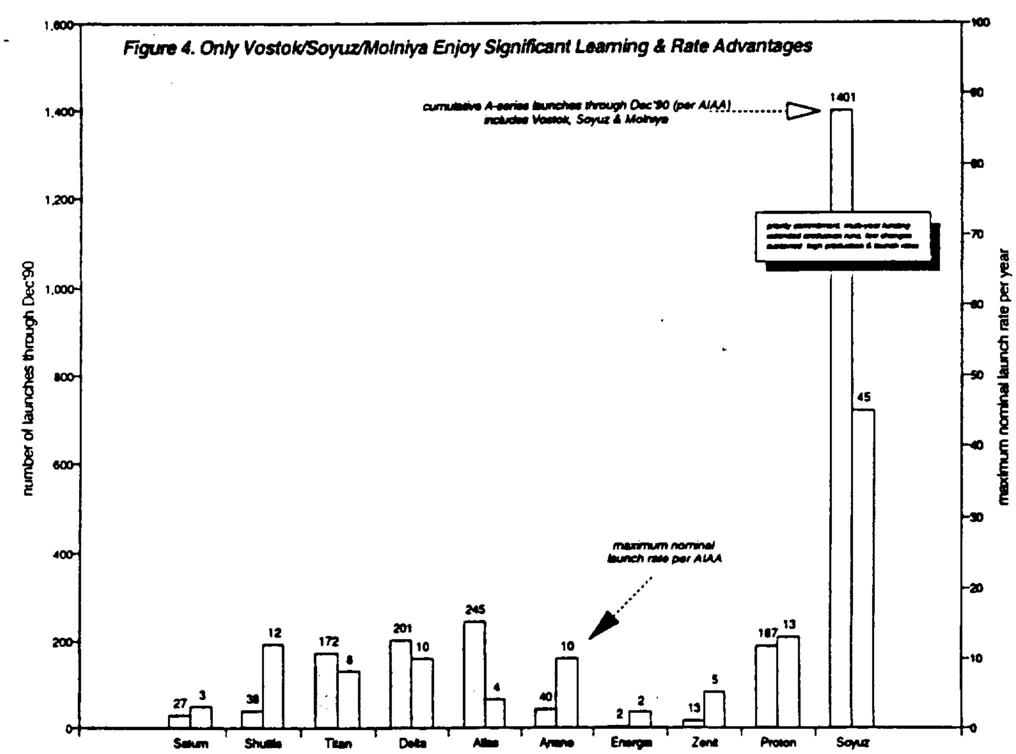


Figure 3.3-6 Soyuz Class Boosters have Significant Learning & Rate Advantage

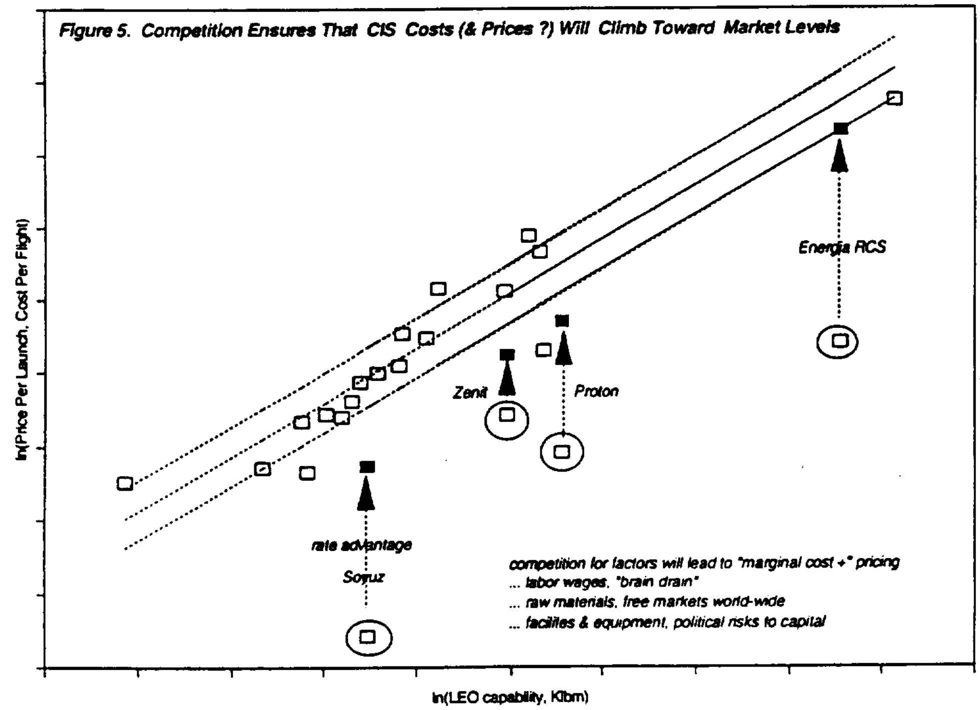


Figure 3.3-7 Competition will Force CIS Costs to Climb to Market Levels

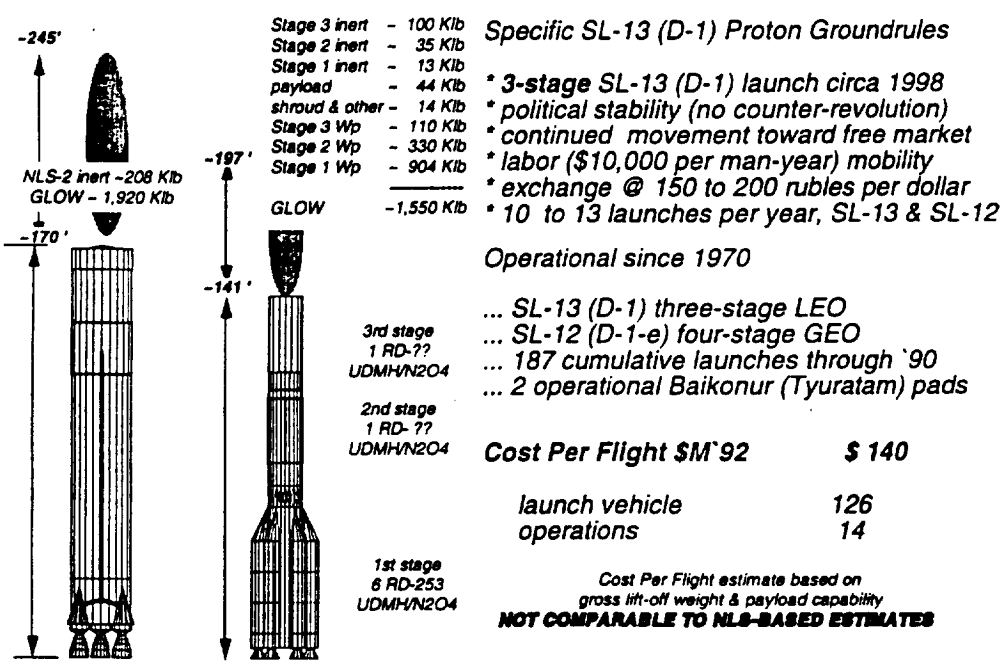
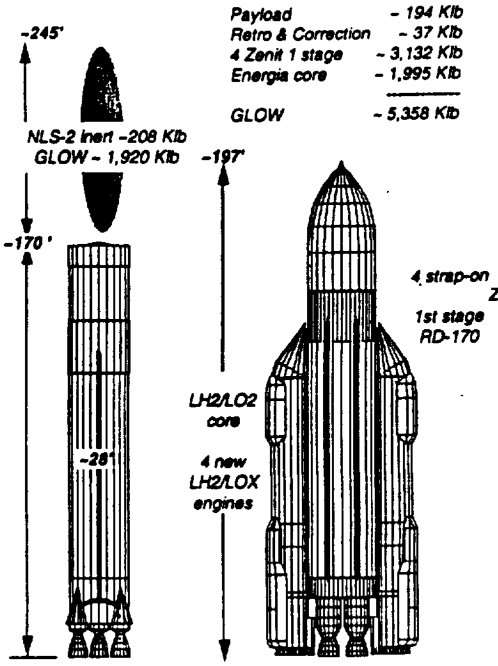


Figure 3.3-8 CIS SL-13 Proton Launch Vehicle



Specific SL-17 Energia Groundrules

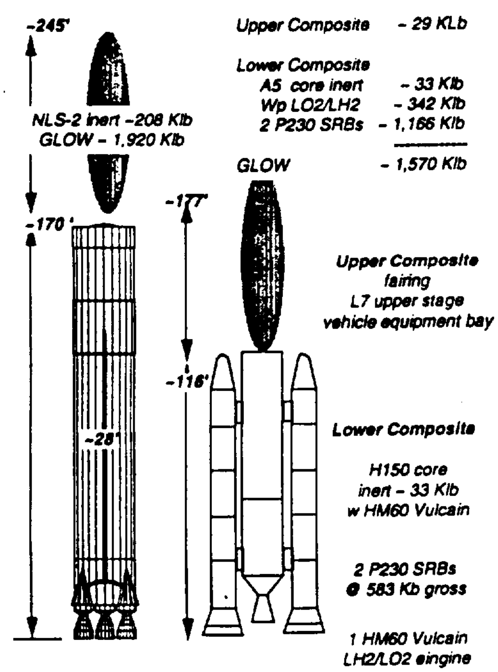
* baseline SL-17 w 4 strap-on boosters
* annual fight rate ... 1
* assume program not cancelled
* only flown twice, once with Buran
* does not include Buran or crew ops

Development: reported to have cost ~ 10 to 15 billion rubles over 15 years

Cost Per Flight $M'92		**$ 516**
launch vehicle	413	
operations	103	

Cost Per Flight estimate based on gross lift-off weight & payload capability
NOT COMPARABLE TO NLS-BASED ESTIMATES

Figure 3.3-9 CIS Energia Launch Vehicle



Specific Ariane 5 Groundrules

* commercial launch circa 1998
* '90-'91 average exchange rates
* 50-70 unit production lot buy
* ESA productivity ... capital/labor split
* annual fight rate ... 8 to 12
* profit (loss) incentives

Development Cost $M'92		**$ 5,412**
DDT&E	4,326	
N/R Production	347	
Construction of Facilities	739	

Cost Per Flight $M'92		**$ 90**
launch vehicle	66	
operations	6	
profit (support)	6	
reserves & other direct costs	12	

Cost Per Flight estimate based on gross lift-off weight, payload capability & other data sources
NOT COMPARABLE TO NLS-BASED ESTIMATES

Figure 3.3-10 ESA Ariane V Launch Vehicle

3.3.3 Cost Estimates by WBS Element

ESA's commercial Ariane 5 is currently a developmental system, with an expected initial operational capability (IOC) in 1995. CIS's Soyuz (IOC 1963), Proton (IOC 1968) and Energia (IOC 1987) are currently operational launch systems, and no further development efforts are anticipated.

Summary of Cost Estimates for Ariane 5, Soyuz, Proton & Energia

	Non-Recurring Cost $FY'92M (1)	Cost Per Flight (3) $FY'92M (1)
Ariane 5	$ 5,400	$ 90 @ 10 per year
Soyuz	not applicable (2)	$ 52 @ 40 per year
Proton	not applicable (2)	$ 140 @ 13 per year
Energia	not applicable (2)	$ 51 @ 1 per year

Notes:

(1) Assumes an average $FY'92M exchange at approximately 150 CIS rubles per US dollar and O.8 ESA accounting units per US dollar

(2) Soyuz (IOC 1963), Proton (IOC 1968) and Energia (IOC 1987) are already operational; no further non-recurring are costs anticipated

(3) Cost per flight estimates assume a circa-1998 commercial launch from Kourou (ESA) or Baikonur (CIS)

3.3.4 not applicable

3.4 National Launch System (NLS)-Derived Launch Vehicles

3.4.1 Costing Approach, Methodology & Rationale

Methodology: Parametric

Primary Sources of Data: design-to-cost "goals " per F. D. Bachtel

Groundrules & Assumptions
All costs expressed in $M 1991 (NLS convention) and are based on cost "goals", do not reconcile with cost "estimates"

New Ways of Doing Business: assumed a cost reduction "credit" for NWODB

Test Philosophy: unknown

Operational Philosophy: operated by "airman 2nd"s & "tech sergeants" ...

Number/Kinds of Spares: profuse

Cost Avoidance Techniques: marginal costing

Management Approaches: high risk tolerance, e.g., new, low-cost STME development concurrent with launch vehicle DDT&E

WBS Definition: pictorial

Representative CERs: cost factors Summary of Cost Trades

3.4.2 Summary Cost Presentations

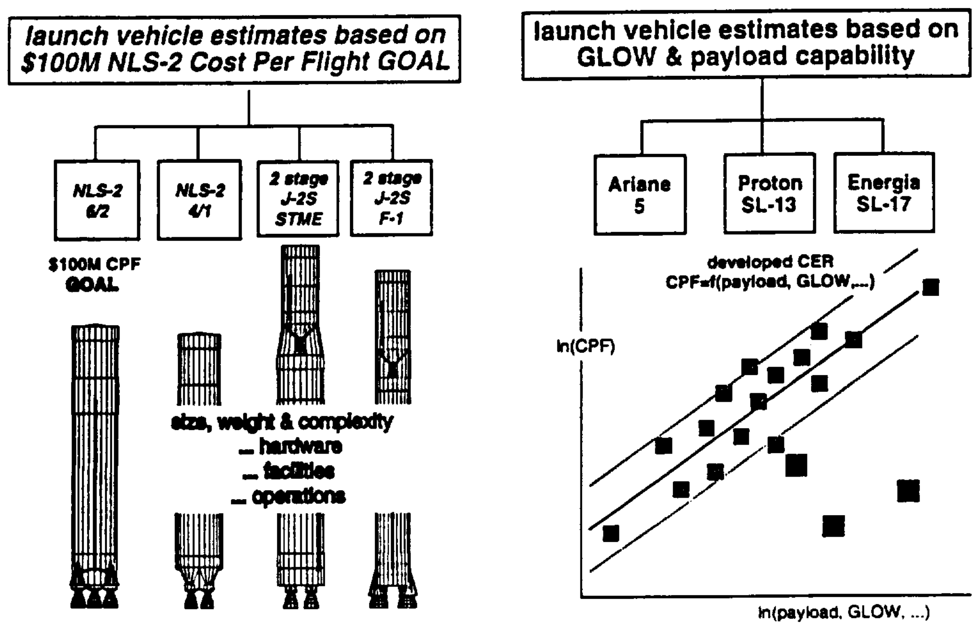


Figure 3.4-1 NLS Costs Not Comparable To Foreign Booster Estimates

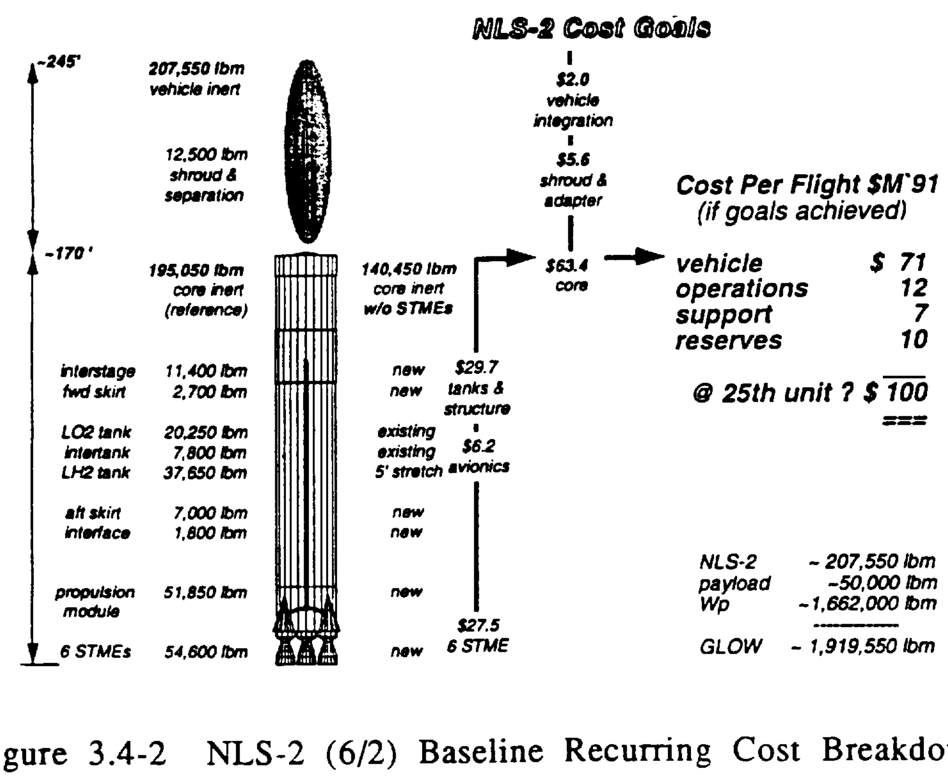


Figure 3.4-2 NLS-2 (6/2) Baseline Recurring Cost Breakdown

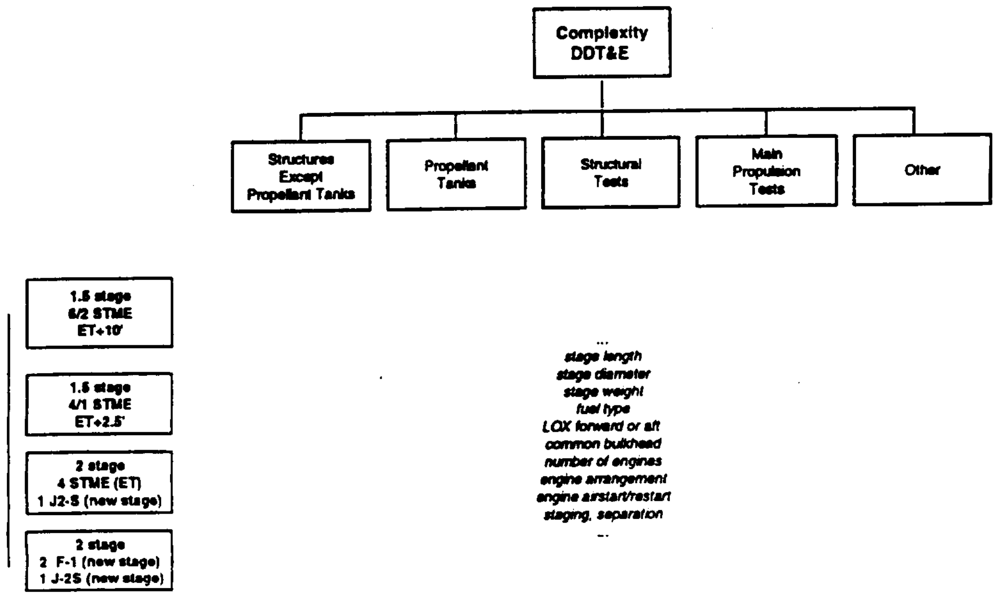


Figure 3.4-3 Development Complexity Factors Based On Engineering Judgment

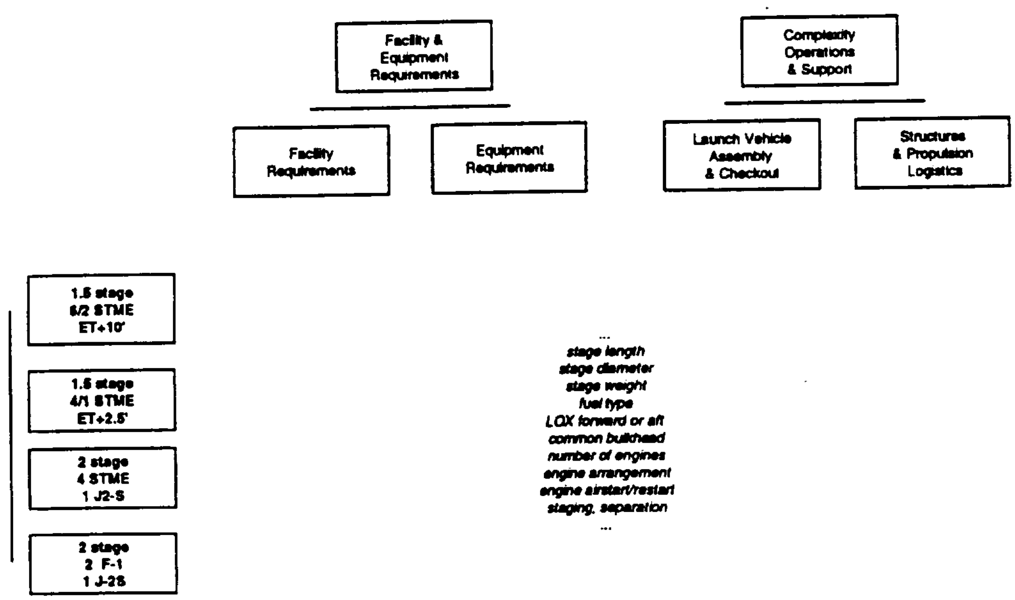


Figure 3.4-4 Facility Requirements & Operational Complexities Were Compared

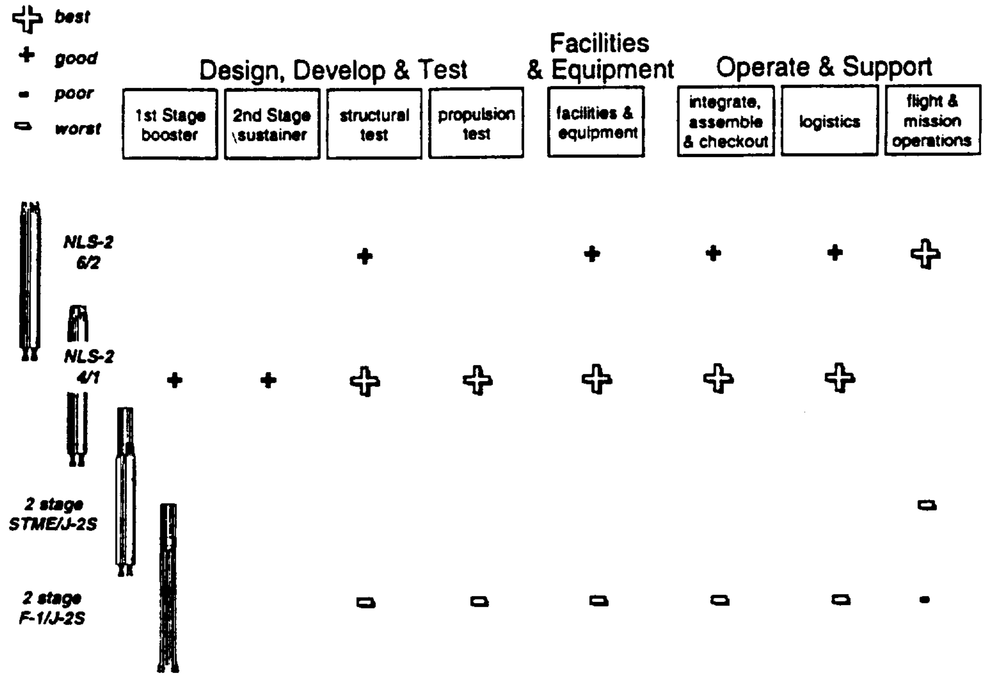


Figure 3.4-5 NLS-2 and Derivative Boosters Complexity Assessment

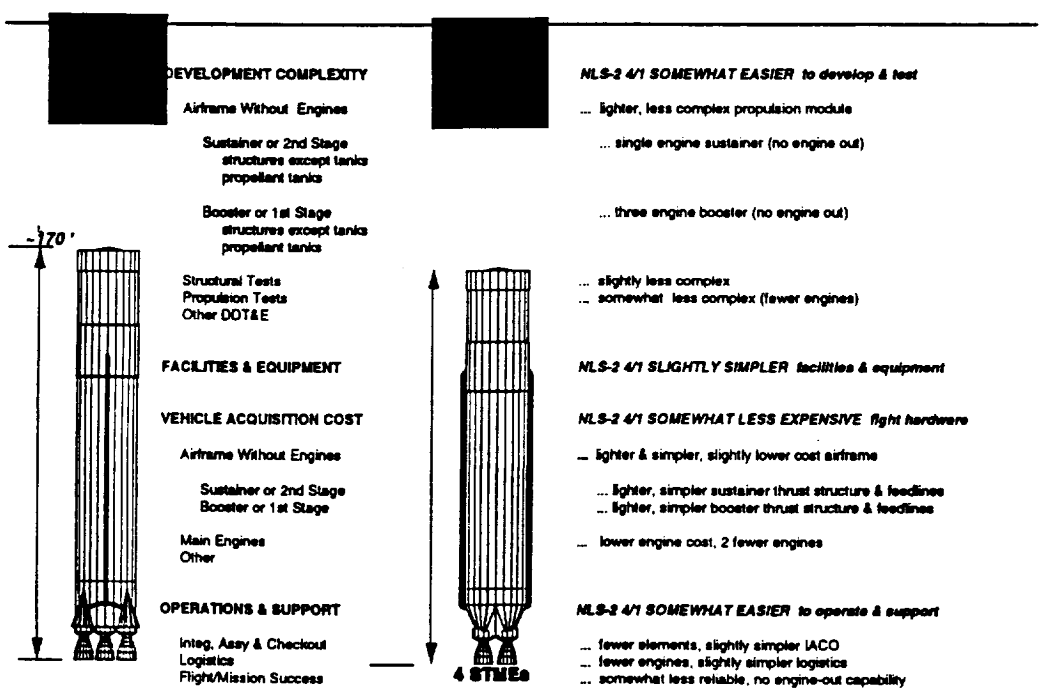


Figure 3.4-6 NLS-2 (6/2) (Engine Out) Compared To NLS-2 4/1 (No Engine Out)

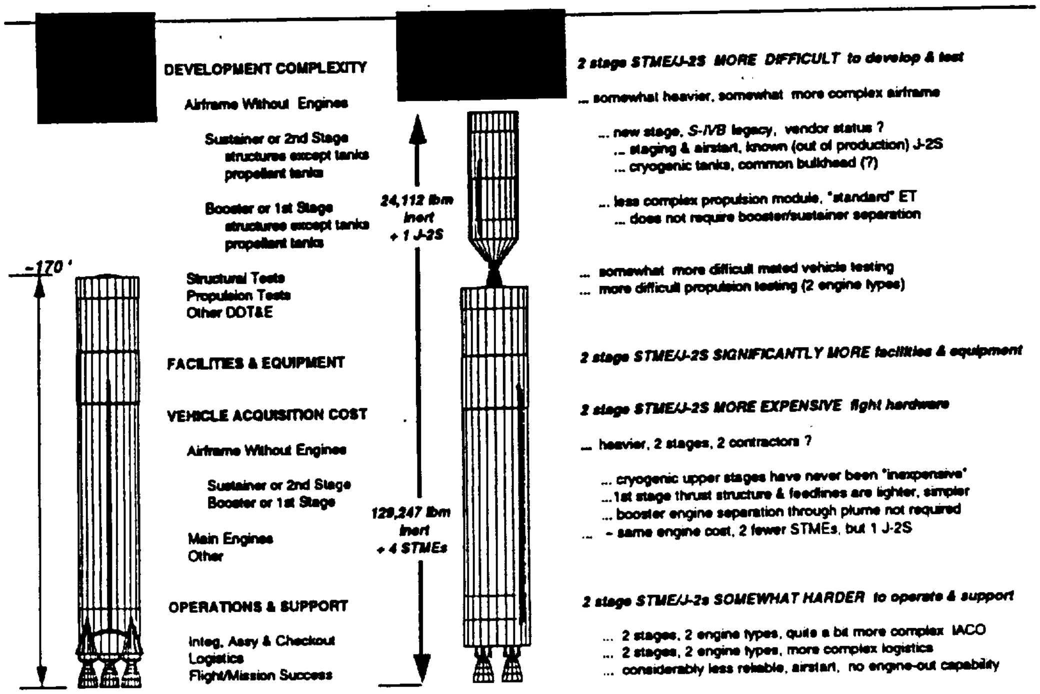


Figure 3.4-7 NLS-2 (6/2) Compared To 2 Stage (4 STMEs + 1 J-2S)

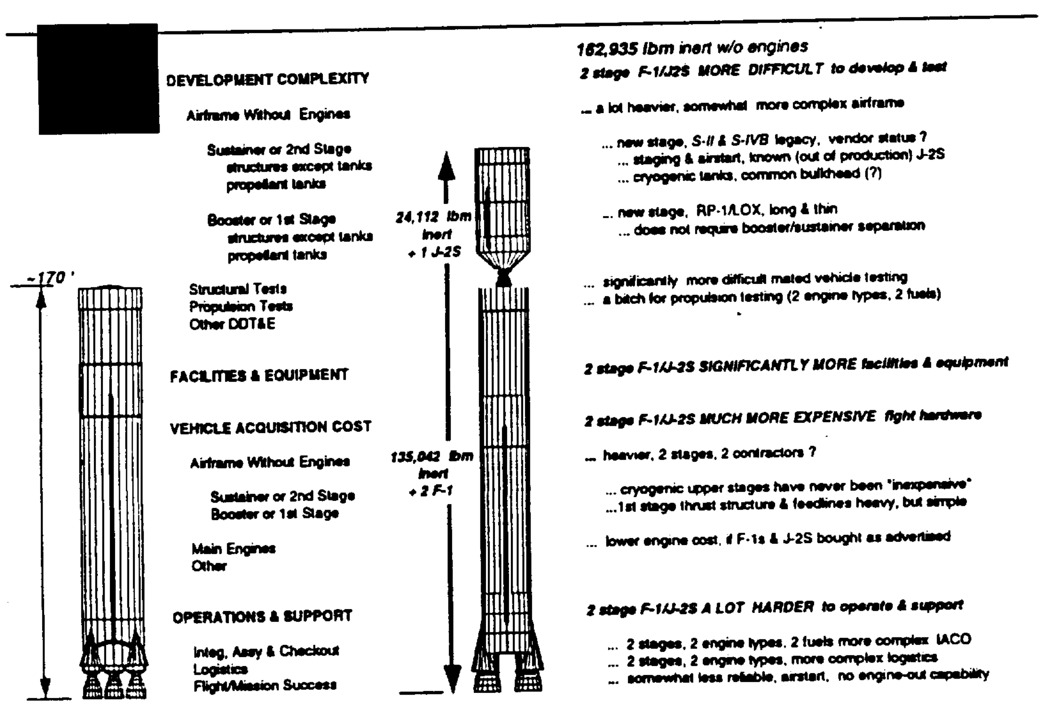


Figure 3.4-8 NLS-2 (6/2) Compared To 2 Stage (2 F-1 + 1 J-2S)

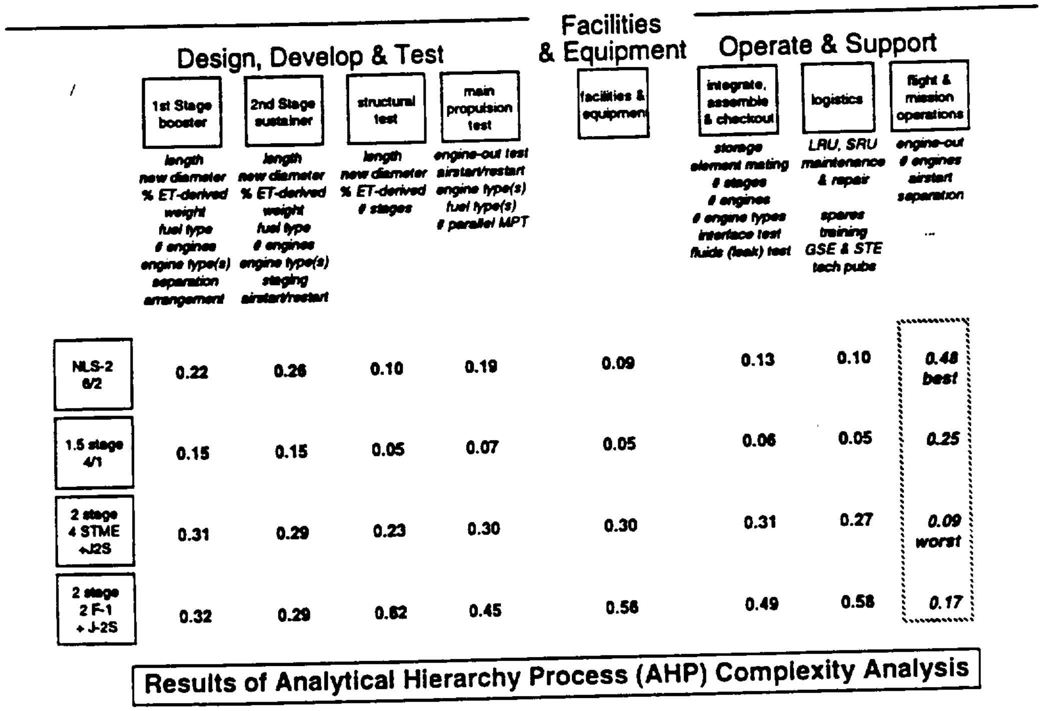


Figure 3.4-9 Results of Analytical Hierarchy Process Complexity Analysis

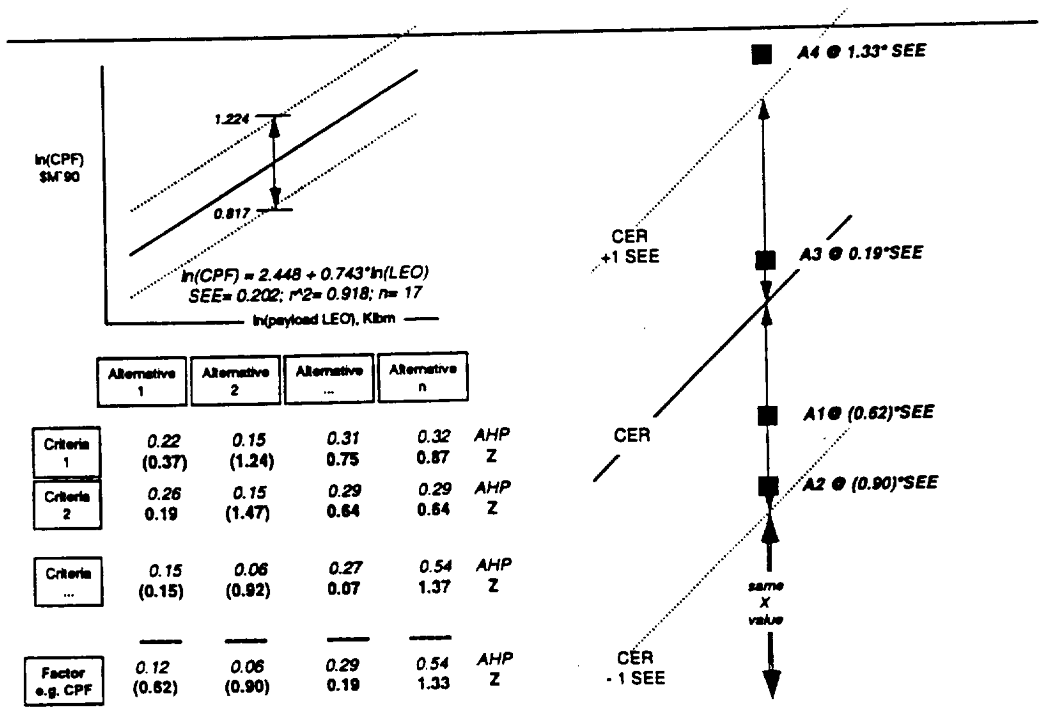


Figure 3.4-10 Statistical "Z score" Converts AHP Complexity Factors To Relative Cost Per Flight

	NLS-2 6/2	NLS-2 4/1	2 stage J-2S STME	2 stage J-2S F-1
hardware complexity	1.00	0.82	1.16	1.27
operations complexity	1.00	0.95	1.18	1.48
hardware %	71	58	82	90
operations %	19	18	22	28
reserves %	10	8	12	13
relative %	100	85	116	132

$100M CPF GOAL

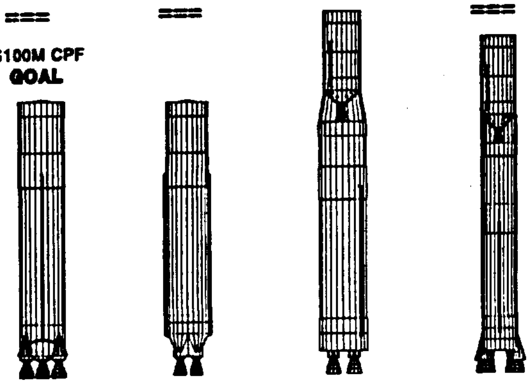


Figure 3.4-12 NLS Derived Booster Costs Based on $100M Cost Per Flight Goal

3.4.3 Cost Estimates by WBS Element

None provided.

3.4.4 Total Program Funding Schedules

None provided.

3.5 Two-Stage Launch Vehicle: LOX/RP F-1A Booster & LOX/LH2 J-2S Second Stage (S-IVB)

3.5.1 Costing Approach, Methodology & Rationale

Estimates for non-recurring design, development, test & evaluation (DDT&E) cost, theoretical first unit (TFU) cost, and cost per flight at the 25th unit were made for a two stage launch vehicle comprised of a booster (first) stage based on Martin Marietta's (MMC's) Liquid Rocket Booster (LRB) concept, an upper (second) stage based on McDonnell Douglas' (MDD's) S-IVB stage for Saturn I-B and Saturn V, and an avionics/interstage equivalent to Boeing's (BA's) instrument unit for Saturn V.

Parametric rough-order-of-magnitude (ROM) estimates were based on available (sketchy and sometimes internally inconsistent) weight data for all stages, using analogies to historic actual costs and/or available subsystem-level cost estimating relationships (CERs). Given the aforementioned limitations, only moderate confidence (perhaps within 25% or so) should be ascribed to the estimates.

3.5.2 Summary Cost Presentations

None made

3.5.3 Cost Estimates by WBS Element

WBS Cost Element	Weight (lbm)	N-R M'93	TFU M'93	25th M'93
Construction of Facilities		**419**		
Launch Vehicle	**1,425,921**	**4,807**	**359**	**244**
Launch Operations			39	26
Mission (Flight) Operations			15	10
Indirect Wraps		**2,021**	**75**	**51**
Contractor's fee		370	27	
Program Support		740	13	
Vehicle Integration (prime)		176	13	
Contingency		587	23	
Launch System Software		149		
Launch Vehicle Hardware	**159,381**	**2,786**	**230**	**156**
Instrument Unit	115			
Stage 2 (S-IVB)	31,571			
Stage 1 Booster	123,310			

Comment: This concept achieves its relatively superior performance (payload to low Earth orbit is roughly 4% of gross lift-off weight, which is unusually high for a 1,425,000 pound "stack") largely as a result of its extremely costly (performance optimized) S-IVB second stage. If this concept is pursued any further, upper stage cost versus upper stage performance should become a primary tradeoff.

3.5.4 Total Program Funding Schedule

Not estimated

3.6 Cargo Transfer & Return Vehicle (CTRV)

3.6.1 Costing Approach, Methodology & Rationale

Cost estimates were not provided by the ATSS contractor for the several CTRV concepts examined during the study. Development and operational cost estimates for the CTRV concepts were provided by NASA as part of the Access to Space (Option 2) study. The ATSS study did provide cost estimating factors and CTRV design information to NASA for use in their cost estimating activities. A Design Complexity factor and a Percent New Design factor were defined for the CTRV cost estimates. These factors were used by all NASA centers to provide a common cost estimating basis for the many CTRV concepts under study. Weight estimates were provided to NASA for those CTRV concepts which the ATSS contract designed (see ATSS Final Report (DR-4) for CTRV weight data provided in support of cost estimates).

Design Complexity
This cost factor compares the functional requirements and performance specifications that have been imposed on the hardware/software item to be costed to items which comprise the cost estimating database. The factor assumes that added functions and/or higher performance manifest themselves in the forms of compound or complex geometry, larger physical dimensions, exotic materials, higher parts count, increased level of redundancy, more extensive test & verification programs, etc.

Factor	Definition of Design Complexity Factor
>1.0	hardware/software required to provide more functions or meet higher performance specifications than items included as basis of estimate
1.00	hardware/software which performs essentially identical functions and meets essentially identical performance specifications as items included as basis of estimate
<1.00	hardware/software required to provide fewer functions or meet lower performance specifications than items included as basis of estimate

Percent New Design
This factor describes the level of competence and/or experience which exists in designing, developing, testing, and evaluating (DDT&E) the hardware or software item.

Factor	Definition of % New Design Factor
1.00	Analogous hardware components or software items do not exist. No relevant DDT&E experience. Unproven technology (TRL 4 or 5).
0.80	Analogous hardware components or software items do exist but were developed by others. No direct DDT&E experience, but the technology can be acquired (literature or personnel). Immature technology (TRL 5 or 6), technology readiness demonstrations are required.
0.60	Very limited DDT&E experience with similar items exists. Some new technology implemented in the design (TRL 6 or 7).
0.40	Considerable DDT&E experience with very similar (function) items exists. Major modifications (scale or application) of existing hardware/software is required. Mature technology, materials and processes are well understood.
0.20	Extensive DDT&E experience with essentially identical items exists. Minor modifications (scale or application) of existing hardware/software is required. Mature technology, materials and processes are well understood.
0.00	"As-is" hardware or software used in identical application and environment.

An example of the use of the Design Complexity and Percent New Design factors are shown for the Winged CTRV concept. NASA used these factors with the CTRV weight estimates for estimating CTRV system costs. The mathematical combination of these factors (straight multiplication, sum of the squares, etc.) may be varied by the cost analyst to best match cost estimating relationships (CERs) for the system being costed and the reference cost database.

Winged CTRV Subsystem/Component	Total Weight (lbs)	Percent New Design	Design Complexity
Thermal Protection System	8,917		
nose cone (ACC)	1,281	0.30	1.00
tiles (HRSI or LRSI)	6,782	0.30	1.00
blankets (TABI or AFRSI)	596	0.20	1.00
misc. (seals, heat sinks,...)	259	0.10	1.00
Thermal Control System	1,846		
radiators	857	0.20	1.00
boilers	69	0.20	1.00
plumbing, valves, etc.	230	0.40	1.00
insulation	690	0.10	1.00
Orbital Maneuvering System	1,493		
thrusters	40	0.40	1.00
tanks (MMH + NTO)	1,156	0.40	1.00
plumbing, valves, etc.	297	0.40	1.00
Attitude Control System	345		
FWD - thrusters	127	0.40	1.00
- tanks (He)	0	0.40	1.00
- plumbing, etc.	58	0.40	1.00
AFT - thrusters	127	0.10	1.00
- tanks (MMH + NTO)	0	0.40	1.00
- plumbing, etc.	35	0.40	1.00
Electrical Power Generation	2,156		
batteries	242	0.40	1.00
fuel cells	587	0.20	1.00
fuel cell reactant storage	959	0.20	1.00
plumbing, valves, etc.	368	0.40	1.00
Electrical Power Distrib	1,909		
power distrib/controllers	230	0.60	1.20
wire harnesses	1,679	0.40	1.00
Avionics Systems	1,224		
GN&C	846	0.60	1.00
Comm & tracking	378	0.40	1.00
Data processing	0	0.40	1.20
Instrumentation	0	0.40	1.20
Rendezvous radar	0	0.20	1.00
Environmental Control	704		
purge ducts	106	0.20	1.00
vent doors	598	0.20	1.00
Landing Systems	4,784		
landing gear	3,588	0.40	1.00
actuators/mechanisms	1,196	0.60	1.00
Structures	20,150		
Fwd fuselage	4,500	0.60	1.00
Mid fuselage	4,670	0.20	1.00
Aft fuselage	3,190	0.60	1.00
Payload bay doors	2,770	0.10	1.00
Door hinges/latches	1,130	0.10	1.00
Wings	3,890	0.60	1.00
CTRV Dry Weight	43,527		
Consumables	11,763		
Payload	42,500		
CTRV Launch Weight	97,790		

Figure 3.6-1 Winged CTRV Cost Estimating Factors

3.6.2 Summary Cost Presentations

None prepared.

3.6.3 Cost Estimates by WBS Element

None made

3.6.4 Total Program Funding Schedule

Not estimated